48p

# COMPUTER CODES FOR THE EVALUATION OF SPACE RADIATION HAZARDS

## VOL. 4. SPACE RADIATION DOSES FROM ELECTRON BREMSSTRAHLUNG RADIATION

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## GENERAL INFORMATION

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### PURPOSE

This IBM 7090 FORTRAN program calculates the Bremsstrahlung[1] radiation dose received through several slabs of shield material. Bremsstrahlung radiation is a form of X-ray created when high energy charged particles are slowed down by a material. This program considers only electron-produced Bremsstrahlung.

Required inputs to this program are:

The incident electron spectrum

Photon attenuation coefficients

Build-up coefficients

Shield materials and thicknesses, and solid angles

Flux to dose conversion factors

The calculated dose is called the electron Bremsstrahlung radiation dose and is computed in equation (2).

The program may also be used to estimate the Bremsstrahlung radiation dose received by men or equipment inside a vehicle situated in a region of electron radiation. To perform these calculations, the program requires a resolution

(over)

1. The electromagnetic radiation emitted by electrons when they pass through matter. The continuous spectrum of X-rays from an X-ray tube is that of Bremsstrahlung (from the German bremse=brake, strahlung=radiation; namely the radiation given off as an electron is slowed or braked in traversing matter).

Author

of all material in the vehicle into an equivalent polyhedral shell.[2] Each side of a shell is described by the solid angle it subtends from the dose receiver point and the materials and their thicknesses of that side (see Figure 1). By considering human tissue as part of the shielding, doses may be calculated at points inside the human body. If the vehicle configuration is not complex (can be assumed to be of uniform thickness over large regions), the resolution into a polyhedron is obviated. This will be discussed further in the section on Input Preparation and Output Description.

## ASSUMPTIONS

The method of solution used in the program depends on several assumptions. The Bremsstrahlung radiation is assumed to be generated on the surface of the outermost shield layer and no electrons penetrate this surface. This assumption is justified by the fact that the Bremsstrahlung is much more penetrating than incident electrons. Actually, Bremsstrahlung originates at any depth of the material but with exponentially reduced intensity as depth increases.

Bremsstrahlung is treated as a parallel beam source of infinite area with semi-infinite slab shielding. To account for the additional dose from scattered radiation, empirical buildup factors were used. Angular distribution of the source is accomplished with a weighting factor. For successive shielding layers, the dose buildup was assumed to be multiplicative. In the calculations of doses

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2. A figure or solid formed by four more plane surfaces.

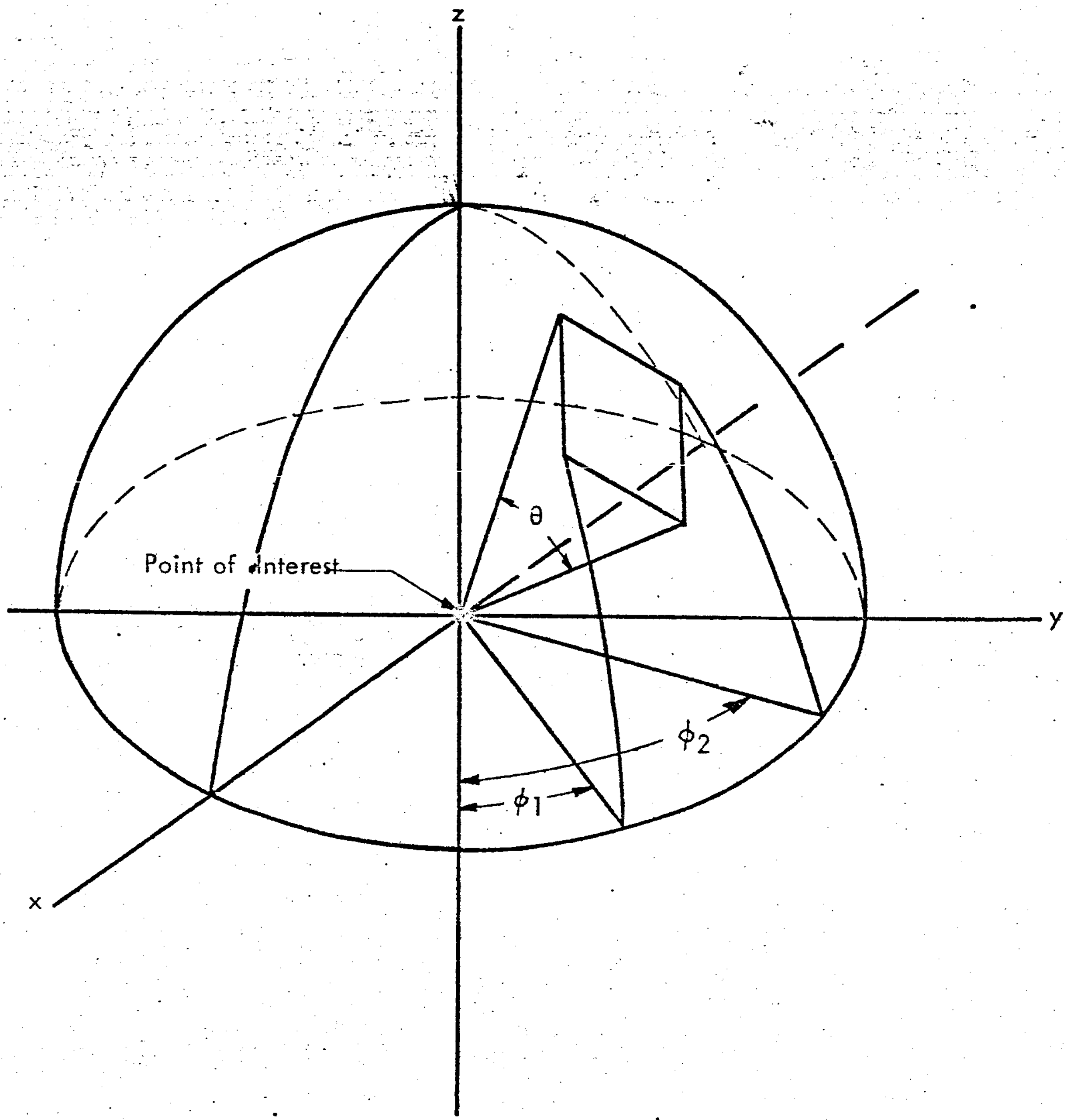


FIGURE 1. Vehicle resolved into equivalent polyhedral shell configuration.

inside a vehicle, the same assumptions apply to each side of the approximating polyhedron mentioned previously. The photon energy spectrum is assumed to be independent of the outer shield layer composition.

## LIMITATIONS

The incident electron spectrum must be analytically defined as a function of electron energy. Only twelve or less shield materials may be considered at one time. Attenuation coefficients and coefficients determining the dose buildup factors as a function of photon[3] energy and shield material are tabulated inputs with at most 100 energy points allowed. Dose conversion factors are tabulated inputs with the energy points being the same as for the above coefficients. A polyhedron of no more than 350 sides may be used to represent a vehicle.

## RECOMMENDATIONS

It is recommended that the program be modified to handle Bremsstrahlung photon production which varies with the shield material of each layer. Recently, by the use of another computer program, Bremsstrahlung production in multi-element slabs has been investigated. These results indicated that shield material has an effect on the Bremsstrahlung production when the slab is thinner than the range of an electron.

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3. An indivisible quantity of electromagnetic energy. Sometimes called a light quantum.

## PROCEDURE

### NOMENCLATURE

The nomenclature is presented in Table 1.

### METHOD

The theory for these calculations is reported in Ref. 1.

This section is divided into two parts: the first part is a discussion of the procedure for calculating the Bremsstrahlung dose for semi-infinite slab shielding; the second part treats the procedure of performing an actual vehicle shielding analysis.

<u>Procedure for Calculating the Bremsstrahlung Dose for Simi-Infinite Slab Shielding</u>

Computation of the dose from secondary photons, produced by electron interactions with matter, can be described in the following way. Electrons of a given energy produce Bremsstrahlung photons of various energies. Only a fraction of the incident electron energy is converted to photon energy. Photons are absorbed as they are transmitted through layers of material. If the dose from photons of all energies arising from electrons is considered, one may write:

$$D = S \int_{\gamma_L}^{\gamma_u} T(\gamma)K(\gamma)\left[\int_{\gamma}^{E_u} N(E)W(E)F(E,\gamma)dE\right]d\gamma \qquad (1)$$

where: D = photon dose received in a region

TABLE 1. Nomenclature

| Mathematical Symbol | Program Symbol | Explanation |
|---|---|---|
| E | EE, E | Electron energy in Mev (million electron volts) |
| $\gamma$ | EF | Photon energy in Mev |
| N | ELSI | A function subroutine name, also the electron differential spectrum in electrons/Mev/$cm^2$ |
| Z | Z | Atomic number of shield material |
| W | CONGO | Fraction of electron energy which is converted to photon energy, also name of a function subroutine |
| F | | Photon differential energy spectrum in Mev/Mev |
| i | I2 | Shield sector index |
| j | J | Shield layer index |
| D | DOSV, TVDOSE | Photon dose |
| S | SOURCE FACT | Electron source, in electrons/$cm^2$ |
| T | PISUM | Photon energy transmission |
| K | DOSCON | Energy flux to dose conversion factor |
| g | SINGL | Arbitrary function |
| f | FUNCT | Arbitrary function |
| X | T | Material thickness, in gm/$cm^2$ |
| $\mu$ | AU, AUNM | Mass attenuation coefficient |
| B<br>b | B1, B3<br>B2, B4 | Coefficients in dose buildup factor |
| $\Delta\Omega$ | DOMEGA | Solid angular increment/$4\pi$ (weighting factors) |

$S$ = total number of electrons passing into the outermost layer per unit area of shield surface

$E$ = electron energy

$\gamma$ = photon energy

$N(E)$ = electron differential number spectrum (number of electrons having energy between $E$ and $E+\Delta E$ divided by $\Delta E$)

$W(E)$ = fraction of electron energy converted to photon energy

$F(\gamma, E)$ = total energy of all photons having energy between $\gamma$ and $\gamma + \Delta\gamma$ divided by $\Delta\gamma$, arising from electrons of energy E

$T(\gamma)$ = fraction of photon energy transmitted through the shield layers; a function of photon energy (dependent on material thickness)

$K(\gamma)$ = conversion from photon energy/unit area to units of dose for photons of energy $\gamma$

$E_u$ = upper limit on electron energy

$\gamma_L$ = lower limit on photon energy

$\gamma_u$ = upper limit on photon energy

For each shield layer configuration, the photon dose in a region behind the shielding is evaluated by the use of a special purpose integration subroutine DITTO (Ref. 2). In order to use subroutine DITTO, the dose formula is rewritten as:

$$D = S \int_{\gamma_L}^{\gamma_u} g(y) \left[ \int_{y}^{E_u} f(x, y)\, dx \right] dy \qquad (2)$$

where g(y) and f(x) are expressed in the program as function subprograms with both g(y) and f(x, y) being continuous functions and

$$g(y) = T(y)\, K(y)$$

$$f(x, y) = N(x)\, W(x)\, F(x, y)$$

In the computer program, the function $g(y)$ is called SINGL and the function $f(x, y)$ is called FUNCT. Versatility has been added to the program by letting $N(x)$ and $W(x)$ be described by separate function subprograms ELSI and CONGO.

At this point, the various terms in the formula will be stated explicitly. The dose D, electron energy E, and photon energy $\gamma$, conversion factor K, and the limits of integration are self-explanatory. Particular attention is given the transmission function T.

Calculation of the fraction, T, of photon energy transmitted through a shield is performed by using a formula having two arguments, photon energy and material thickness. Parameters involved also depend on material composition.

$$T = \prod_{j=1}^{N_x} \left[ e^{-\mu_j X_j} \left( B_{1j}\, e^{-b_{1j}\mu_j X_j} + B_{2j}\, e^{-b_{2j}\mu_j X_j} \right) \right] \tag{3}$$

where: T = energy transmission through a number of shield material layers ($N_x$)

$X_j$ = thickness of material j, expressed in gm/cm$^2$

$\mu_j$ = mass attenuation coefficient, for material j and a given photon energy, expressed in cm$^2$/gm

$B_{1j}$, $b_{1j}$, $B_{2j}$, $b_{2j}$ = buildup coefficients for material j and a given photon energy

$\prod_{j=1}^{N_x}$ = the product of the enclosed expression for each layer i, where $j = 1, 2, 3, \ldots, N_x$

Buildup coefficients and mass attenuation coefficients make up tabulated arrays, their elements depending on photon energy and material composition.

The photon differential energy spectrum, according to Wyard (Ref. 3), is roughly independent of material composition and is expressed as:

$$F = \frac{1}{1.25}\left[4\left(1 - \frac{\gamma}{E}\right) - 3\,\frac{\gamma}{E}\ln\left(\frac{E}{\gamma}\right)\right] \tag{4}$$

where: F = total photon energy of all photons having energy between $\gamma$ and $\gamma + \Delta\gamma$ divided by $\Delta\gamma$, arising from electrons of energy E.

The constant 1.25 is a factor which normalizes the spectrum such that the integrated photon energy just equals the energy E of one electron. This function F is included in the subprogram FUNCT.

The fraction of the electron energy E, which is actually converted to Bremsstrahlung photon energy, is: (Ref. 1)

$$W = \frac{0.000198Z\,(1.96\,E + 2)}{1 + 0.152\ln\left(\frac{82}{Z}\right)} \tag{5}$$

where: Z = atomic number of the outermost shield layer (layer exposed to the electrons)

The function W is computed in subprogram CONGO.

The electron differential number spectrum N(E) is the number of electrons having energy between E and $E+\Delta E$ divided by $\Delta E$. This can also be stated by the relation:

$N(E)\Delta E$ = total number of electrons with energy between E and $E + \Delta E$

It is convenient to normalize such a spectrum to one electron so that:

$$\int_0^{\infty} N(E)\, dE = 1 \qquad (6)$$

In the program, N is specified by the function subprogram ELSI.

Currently, three statements of N are written in ELSI with a selection of one mode at compute time by the input of an index setting n.

N = expression for electrons in the artificial belt[4] for n = 1

N = expression for electrons in the artificial belt[4] for n = 2 (different formula)

N = expression for electrons in Van Allen Belt for n = 3 natural belt

The factor S is used to scale the calculated dose from a normalized electron spectrum to the actual dose. It is composed of two factors: the total external electron flux (expressed in electrons/cm$^2$/sec) and the fraction of the total flux which can enter the shielding materials. Total electron flux may be a time integrated flux if the total dose is desired rather than dose rate.

Procedure for Performing an Actual Vehicle Shielding Analysis

Calculation of dose at points totally surrounded by shielding materials has been formulated as a simple extension to the infinite plane slab calculations. The portion of the program which performs such an analysis is entered optionally. This calculation is important in the estimation of Bremsstrahlung radiation doses

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4. This belt was caused by high altitude weapon tests.

received by men and equipment on board space vehicles. Simply stated, the scheme is to perform the dose calculations for a set of slab problems, then compute a weighted sum of these doses. Thus:

$$D_v = \sum_{i=1}^{N_p} D_i \, \Delta\Omega_i \quad (7)$$

where $D_v$ = dose received at a prescribed point inside the shield configuration

$D_i$ = dose for the infinite slab shielding case number $i$.

$\Delta\Omega_i$ = increment of solid angle for slab shielding case number $i$, divided by $4\pi$.

This weighting factor $\Delta\Omega$ is equivalent to the fraction of total solid angle subtended by a particular region of the surrounding shielding as seen from the dose point. That the total dose at points completely surrounded by shield materials may be calculated in the manner described has been shown in Ref. 4. Weighting factors used in a vehicle analysis are discussed further under Input Preparation.

## RESULTS

To check the validity of this program, comparisons were made with data published by C. D. Zerby and H. S. Moran (Ref. 5). Although the cases run for comparison were not identical to conditions used by Zerby and Moran, disagreement was, as expected, relatively small. Their data was tissue dose rate from Bremsstrahlung radiation with an idealized Apollo vehicle wall exposed to electrons in the artificial radiation belt.

## INPUT PREPARATION AND OUTPUT DESCRIPTION

### INPUT DATA PREPARATION

In preparing for a computer run of this program, two broad categories of effort are required. First, it is necessary to determine the materials and their thicknesses observed through any sector of the vehicle. The results of this will be a set of weighting factors, shield layer thicknesses, and shield layer materials.

Secondly, the various parameters which specify the shielding properties of the materials involved, the units of dose, and electron energy spectrum of the environment must be specified. This collection of information constitutes the major part of the program input. The following paragraphs describe in detail the normal procedures for obtaining this data. Directions for preparation of input data cards are stated by comments in the program listing.

### SHIELD CONFIGURATION

The entire structure of a vehicle, outer fuselage and interior components are observed from the point of interest, i.e., the dose point. From this point, the structure is broken into solid angular regions. The basis for selection of regions is that the materials and their thicknesses be uniform in each region. For each region, the thickness of every layer of material intersected by a line from the dose point to a point outside the vehicle is calculated. The thickness mentioned is equal to the length of the line segment which lies inside the layer. Such thicknesses are expressed in terms of optical depth (material density multiplied by the thickness). Types of material in each layer (in particular, the atomic number) is recorded for each layer, where the layers are numbered with the outward layer being number one. Finally, the weighting factor for the region is calculated as the solid angle representation of the region divided by $4\pi$. This number is then equivalent to the fraction of total solid angle occupied by this region. Note that the sum of all weighting factors should be unity. Usually, the vehicle will have some axis of symmetry which facilitates the task of sectoring.

## PARAMETERS AND TABLES

The various parameters and tables of material properties are determined from a knowledge of the radiation environment and the materials which exist in the shield layers. From the radiation environment, the shape and magnitude of the incident electron spectrum is determined. If the spectrum shape is one of those calculated in the existing subroutine ELSI, only the index number, N, is needed. However, any spectrum can be inserted in that routine if a suitable expression of N(E) can be formed.

The limits of integration are set as the highest electron energy present in the spectrum and the lowest photon energy which will penetrate the thinnest shielding in the system. Commonly used values are 0.1 Mev to 10 Mev. Both upper limits from Equation (2) should be the same since the highest Bremmstrahlung energy is just equal to the highest electron energy.

A tabular array of dose conversion factors is prepared which will depend on the units of dose or dose rate desired and the material in which dose is to be measured. The latter is normally human tissue. This array is tabulated versus photon energy, in Mev. Each entry should then convert photon energy flux, in Mev/cm$^2$ sec, at the given energy to dose, e.g., rads/hr. For example, to obtain rads/hr in tissue, the user would obtain values of the mass energy absorption coefficient such as given in Ref. 6. These values would then be multiplied by 3600 sec/hr $1.6 \times 10^{-8} \left(\frac{100 \text{ ergs}}{\text{Mev}}\right)$ to give the required table entries. An abbreviation of the dose rate units stated in HOLLERITH characters is also required as input. These characters appear in the output from the program.

Finally, tabular arrays of dose buildup factor coefficients and mass attenuation coefficients are prepared. These coefficients are tabulated versus photon energy for every material which appears in the shielding configuration. This also includes tissue when dose is desired at some point inside the human body. The order in which the various materials are set up in the data card deck determines the index number for each material. Refer to Ref. 6 for a compilation of attenuation coefficients and Ref. 6 for a compilation of dose buildup factor coefficients. Note that the computer program requires the dose buildup factor to be of the form, $A_1 e^{-a_1 ux} + A_2 e^{-a_2 ux}$. All control parameters are defined in the coded comments found in the program listing. Card formats and input data symbols are also defined in those comments.

## OUTPUT DATA

The printed output from this program (via logical tape 6) is adequately annotated and is self explanatory. Refer to the sample problem output. If a vehicle analysis is not called for, the last page of output for each case will not appear. The first few pages, which list primarily the material properties, appear only once for each computer run. Problem titles are a part of the input for each case so that each case may be given a new title.

## OPERATING INFORMATION

Instructions for program operation are straightforward. The program was designed for operations under a machine FORTRAN monitor system. The input data is expected to be placed on magnetic tape (logical 5) and read according to the FORTRAN READ INPUT TAPE statement. Output printing is done via logical tape 6 using the FORTRAN WRITE OUTPUT TAPE statements. The normal program stop is initiated through the monitor system by the lack of further input data. An error indication is given when extrapolation is required in the calculation of dose buildup, attenuation coefficients, or dose conversion factors, only if the extrapolation indicator is set in the input data.

## PROGRAMMING INFORMATION

### PROGRAM REQUIREMENTS

Total storage requirements and subroutines specified by the program are stated here. The main program and subroutines not obtained from a normal FORTRAN library require a total of 11,940 locations. This is split into 7,458 COMMON storage locations and 4,482 locations for the instructions and NON-COMMON data storage. Subroutines required from the library include:

| | |
|---|---|
| EXP | exp(X) |
| LOG | ln(X) |
| EXIT | returns control to Monitor |

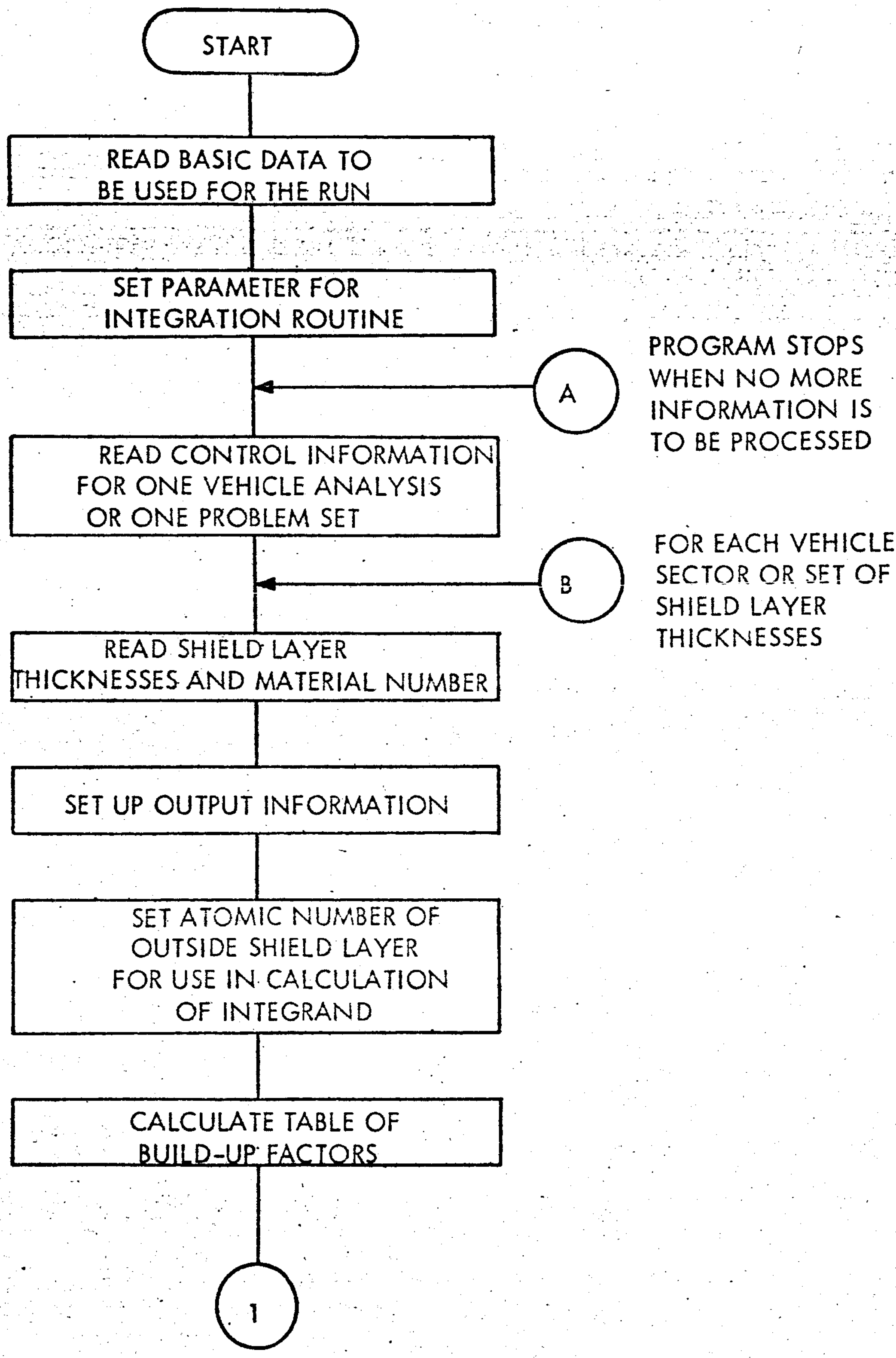
Also required are those routines used by the FORTRAN system for input and output of data.

Subroutines considered part of the program itself are:

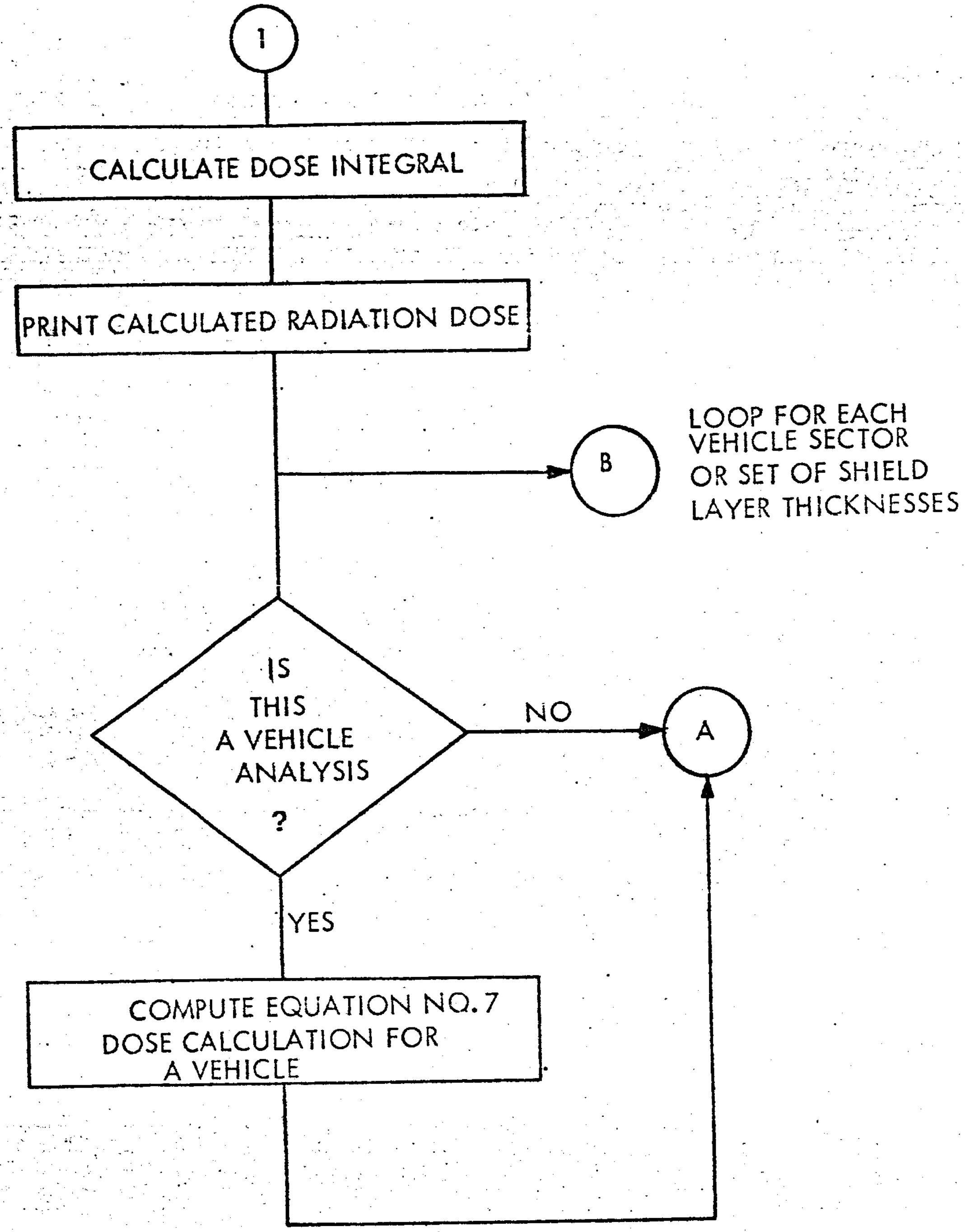
| | |
|---|---|
| INPUT | reads fixed data and parameters which are not changed during run |
| ELSI | described on page 10 |
| CONGO | described on page 10 |
| FUNCT | described on page 10 |
| SINGL | described on page 10 |
| GUESS | a table lookup and interpolation routine |
| DITTO | a specialized double integral routine described in Ref. 2 |

FLOW CHARTS

Macro Flow Diagram for Bremsstrahlung Program



Macro Flow Diagram for Bremsstrahlung Program (cont'd)



# PROGRAM LISTING

```
      DIMENSION PROB(12),CELEM(12)
      DIMENSION Z(12),BU(100,12),AU(100,12),DOSCON(100),EF(100),T(12),
     1LOC(12),BUNM(12),AUNM(12),B(12),M(12)
      DIMENSION B1(100,12),B2(100,12),B3(100,12),B4(100,12),DOSV(350),
     1DOMEGA(350)
      DIMENSION ELEM(12)
      COMMON NEXA,Z1
      COMMON EE,BU,AU,DOSCON,NTBL,NM,NX,Z,T,XU,EEL,YU,EF
      COMMON B1,B2,B3,B4,M
      COMMON ELEM,ADOSEC
C     ****************************************************************
C     ****************************************************************
C ..........CARDS  1 THRU 7 ARE READ BY  SUBROUTINE  INPUT
C  CARD    1                                                  FORMAT
C     NM= NUMBER OF MATERIALS                                     I6
C     NTBL=NUMBER  OF  PHOTON ENERGY TABLE ENTRIES                I6
C     XU=UPPER   LIMIT OF ELECTRON ENERGY                      E12.0
C     YL= LOWER  LIMIT OF PHOTON ENERGY.IT IS ALSO THE IMPLIED E12.0
C     LOWER LIMIT OF ELECTRON ENERGY
C     YU=UPPER   LIMIT OF PHOTON ENERGY                        E12.0
C     NEXA=ANY NUMBER IF ENTRAPOLATION IS ACCEPTABLE ON THE BUILDUP  I6
C       COEF. THE ATTENUATION COEF OF PHOTONS AND THE DOSE CONVERSION
C       FACTORS
C  CARD    2
C     EF(I)=PHOTON ENERGY ENTRIES.THERE WILL BE NTBL ENTRIES    6E12.0
C     CARDS OF TYPE 3,4,AND 5 MAKE 1 SET FOR EACH
C     MATERIAL AND ARE REPEATED AS A SET FOR EACH MATERIAL
C  CARD    3
C     ELEM= NAME OF MATERIAL                                      A6
C     Z=ATOMIC NUMBER OF MATERIAL                              E12.0
C  CARD    4
C     B1,B2,B3,B4,ARE  BUILD UP COEF OF PHOTON ENERGY PER MATERIAL4E12.0
C     THERE WILL BE NTBL CARDS PER MATERIAL.
C     THERE WILL BE A MAXIMUM OF NM TIMES NTBL CARDS
C     OF TYPE 4. IF NO ENTRIES ARE MADE, STACK
C     BLANK  CARDS AS NECESSARY. COEF ARE DIMENSIONLESS
C  CARD    5                                                  FORMAT
C     AU(I,IM)=MATERIAL ABSORPTION COEFFICIENTS. THERE WILL BE  6E12.0
C     SIX,(6) ENTRIES PER CARD. THERE WILL BE NTBL/6 CARDS
C     FOR ONE MATERIAL
C     THERE WILL BE A MAXIMUM OF NM TIMES
C     (NTBL/6) CARDS.
C  CARD    6
C     COMMENT CARD INDICATING UNITS OF DOSE RATE  RAD/HR..ETC  A6
C  CARD    7
C     DOSE  CONVERSION FACTORS. SIX  ENTRIES PER CARD  WITH A   6E12.0
C     MAXIMUM OF NTBL/6 CARDS. THESE FACTORS CONVERT ENERGY FLUX TO
C     DOSE RATE. CARD 6 INDICATES THE UNIT OF DOSE OR DOSE RATE
C ..........CARDS  8 AND ON ARE READ BY  THE MAIN  PROGRAM
C ..............SPECIFIC  PROBLEM  INPUT..........
C  CARD    8
C     COMMENT CARD FOR INFORMATION PERTAINING TO THIS PROBLEM 12A6
C  CARD    9
```

```
C     NP=NUMBER OF SECTORS
C     NV= MINUS NUMBER. A VEHICLE ANALYSIS WILL BE  PERFORMED          I6     0057
C     IF NV IS NOT A MINUS NUMBER,NO VEHICLE ANALYSIS WILL BE                 0058
C     PERFORMED                                                               0059
C     N=1,2,3,4, OR 5, A NUMBER INDICATING THE DESIRED SPECTRUM
C     IF N=1,THE SPECTRUM IS (7.0995E+8/.10005910E10)*
C     EXPF(-.575*E-.055*EE**2)
C     THIS IS THE  CARTER  ARTIFICIAL  SPECTRUM                               0064
C     IF N=2,THE SPECTRUM IS (7.1E+8/.2599127E09)*EXPF(-1.4*EE)
C     FOR EE
C     GREATER THAN ZERO BUT LESS THAN 2. FOR EE GREATER THAN 2.
C     BUT LESS THAN INFINITY THE SPECTRUM IS (1.5E+9/.2599127E09)
C     *EXPF(-.96)
C     THIS IS  THE  MAR  ARTIFICIAL  SPECTRUM                                 0070
C     IF N=3, THE SPECTRUM IS (1.7E+9/.30009661E09)*EXPF(-5.75KEE)
C     +(8.E+6/.30009661E09)*EXPF(-1.8*EE)
C     THIS IS  THE VAN ALLEN SPECTRUM                                         0073
C     IF N=4OR5, NEW SPECTRA MAY BE  INSERTED  IN  SUBROUTINE  ELSIE          0074
C     AS DESIRED                                                              0075
C     SOURCE = NUMBER OF ELECTRONS/CM**2/SEC INCIDENT UPON
C     THE SHIELD
C     FACT=FRACTION OF ELECTRON FLUX WHICH ACTUALLY ENTERS THE       E12.6    0076
C     SHIELD.FACT IS NORMALLY EQUAL TO .5
C     VEHCLE= COMMENT  SPACE,NAME OF VEHICLE TO BE STUDIED             A6     0060
C     POINT=  COMMENT  SPACE,POINT OF INTEREST WITHIN VEHICLE          A6     0061
C  CARD  10                                                                   0080
C     NX= NUMBER OF LAYERS FOR THIS  PROBLEM                           I6     0081
C     OOMEGA= ASSIGNED WEIGHTING FACTOR FOR THIS SECTOR  OF          E12.0    0082
C     THE  VEHICLE.FOUND BY DIVIDING THE SOLID ANGLE BY 4 PI                  0083
C  CARD  11                                                                   0084
C     M=MATERIAL NUMBER INDEX ACCORDING TO ORDER IN WHICH
C     MATERIAL DATA WAS READ (CARDS 3,4,5)
C     T(J)=LAYER OPTICAL DEPTH IN GM/CM**2                            F6.0    0085
C     THERE  WILL BE NP SETS  OF CARD  11 AND 10                              0087
C     THERE  WILL BE NX CARDS OF TYPE 11                                      0088
C     ***********************************************************             0089
C     THIS IS A FORTRAN PROGRAM
C     INPUT USES TAPE LOGICAL 5                                               0091
C     OUTPUT USES TAPE LOGICAL 6                                              0092
C     INPUT REQUIRES PUNCHED CARDS TO BE CARD TO TAPED AND
C     AND TAPE MOUNTED ON LOGICAL 5
C     INPUT REQUIRES PUNCHED CARDS                                            0093
C     NO SENSE LIGHTS ARE USED                                                0094
C     NO SENSE SWITCHES ARE USED                                              0095
C     IF THE PHOTON ENERGY DOES NOT FALL WITHIN THE PHOTON ENERGY             0097
C     TABLE, A COMMENT IS PRINTED INDICATING THE ERROR AND THE VALUE          0098
C     WHICH EXCEEDED THE TABLE LIMITS                                         0099
C     RUN TIME AVERAGES .5 TO .25 MIN PER CASE                                0100
C     ***********************************************************             0101
      WRITE OUTPUT TAPE 6,906                                                 0102
    1 FORMAT(I6,E12.0)
    2 FORMAT(3I6,18X,E12.0,F6.0,6X,2A6)
  901 FORMAT(12A6)                                                            0112
  902 FORMAT(8HO SECTOR,6X,4HDOSE,6X,37HMATERIALS AND THICKNESSES IN GM/
```

```
      1CM**2/13X,A6)
  903 FORMAT(1H ,I5,4X,E11.4,10X,6(A6,1X,F6.2,1X),/30X,6(A6,1X,F6.2,1X))   0140
  906 FORMAT(1H1,30X,44HELECTRON BREMSSTRAHLUNG RADIATION DOSE STUDY )     0103
  907 FORMAT(1H1)                                                           0109
  908 FORMAT(1H0,30HBREMSSTRAHLUNG  WITH SPECTRUM I3)                       0119
 1043 FORMAT(9H1VEHICLE ,A6,28H ANALYSIS, INTERIOR DOSE AT         ,A6)     0154
 1044 FORMAT(1H0,6HSECTOR,6X,6HDOSE   ,11X,7HD OMEGA)
 1045 FORMAT(2X,I6,4X,E12.5,5X,E12.5)                                       0158
 1046 FORMAT(20HOTHE TOTAL DOSE IS  E12.5,2X,A6,14HWITH SPECTRUM I3)        0160
      CALL INPUT                                                            0104
      AMAG=0.5                                                              0106
      ERR=0.1                                                               0107
  999 WRITE OUTPUT TAPE 6,907                                               0108
      READ INPUT TAPE 5,901,(PROB(I),I=1,12)                                0110
      WRITE OUTPUT TAPE 6,901,(PROB(I),I=1,12)                              0111
      READ INPUT TAPE 5,2,NP,NV,N,SOURCE,FACT,VEHCLE,POINT
      WRITE OUTPUT TAPE 6,908,N                                             0118
      WRITE OUTPUT TAPE 6,902,ADOSEC                                        0115
      IF(NP) 998,998,1199                                                   0120
 1199 DO 1099 I2=1,NP                                                       0121
  104 READ INPUT TAPE 5,1,NX,DOMEGA(I2)
  106 READ INPUT TAPE 5,1,(M(J),T(J),J=1,NX)
      DO 3 J=1,NX                                                           0126
      IM=M(J)                                                               0127
    3 CELEM(J)=ELEM(IM)                                                     0128
      M1=M(1)                                                               0129
      Z1=Z(M1)                                                              0130
      DO 400 J=1,NX                                                         0131
      IM=M(J)                                                               0132
      DO 401 I=1,NTBL                                                       0133
  401 BU(I,J)=B1(I,IM)*EXPF(-B2(I,IM)*AU(I,IM)*T(J))+B3(I,IM)*EXPF          0134
     1(-B4(I,IM)*AU(I,IM)*T(J))                                             0135
  400 CONTINUE                                                              0136
      H=(XU-EEL)/10.0                                                       0105
      CALL DITTO(XU,EEL,YU,H,AMAG,N,ERR,DOSV(I2),HX,HY)                     0137
      DOSV(I2)=DOSV(I2)*SOURCE*FACT                                         0138
      WRITE OUTPUT TAPE 6,903,I2,DOSV(I2),(CELEM(J),T(J),J=1,NX)            0139
 1099 CONTINUE                                                              0141
      IF(NV) 1041,999,999                                                   0142
C     VEHICLE ANALYSIS STUDY FOLLOWS                                        0143
 1041 TVDOSE=0.0                                                            0144
      DO 10 I=1,NP                                                          0145
      TVDOSE=TVDOSE+DOSV(I)*DOMEGA(I)                                       0146
   10 CONTINUE                                                              0147
      SUM1=0.                                                               0148
      DO 3942 JK=1,NP                                                       0149
 3942 SUM1=SUM1+DOMEGA(JK)                                                  0150
      TERM=TVDOSE/SUM1                                                      0151
      TVDOSE=TERM                                                           0152
      WRITE OUTPUT TAPE 6,1043,VEHCLE,POINT                                 0153
      WRITE OUTPUT TAPE 6,1044                                              0155
      WRITE OUTPUT TAPE 6,1045,(I,DOSV(I),DOMEGA(I),I=1,NP)                 0157
      WRITE OUTPUT TAPE 6,1046,TVDOSE,ADOSEC,N                              0159
  105 GO TO 999                                                             0161
```

```
998 CALL EXIT                                                         0162
    END(1,0,0,1,0,0,0,0,0,1,0,0,0,0,0)
```

```
      FUNCTION ELSI(EE,N)
                                                                    8/06/63      PAGE 1
      FUNCTION ELSI(EE,N)
      IF(N)1,1,10                                                   0166
   10 GC TO (1,2,3,4,5),N                                           0167
C     THE SPECTRUM ARE OF THE FORM A/INTEGRAL A                     0168
C      CARTER ARTIFICIAL                                            0169
C     ALL SPECTRAM ARE NORMALIZED                                   0170
    1 ELSI=(7.0995E+8/.10005910E10)*EXPF(-.575*EE-.055*EE**2)
      RETURN
C     ARTIFICIAL (N=2) MAR                                          0173
    2 IF(EE-2.0)21,21,22                                            0174
   21 ELSI=(7.1E+8/.2599127E09)*EXPF(-1.4*EE)                       0175
      RETURN
   22 ELSI=(1.5E+9/.2599127E09)*EXRF(-.96*EE)                       0177
      RETURN
C     VAN ALLEN (N=3)                                               0179
    3 ELSI=(1.7E+9/.3000961E+9)*(-5.75*EE)+(8.0E+6/.3000961E+9)*    0180
     1EXPF(-1.8*EE)
      RETURN
    4 CCNTINUE                                                      0182
      RETURN
    5 CONTINUE                                                      0185
      RETURN                                                        0186
      END(1,0,0,1,0,0,0,0,0,1,0,0,0,0,0)                            0187
```

```
FUNCTION CONGO(EE)
COMMON NEXA,Z1
CONGO=   1.98E-4*Z1*(1.96*EE+2.0)/(1.0+0.152*LOGF(82.0/Z1))
RETURN
END(1,0,0,1,0,0,0,0,0,1,0,0,0,0,0)
```

```
      SUBROUTINE GUESS(E,ET,NT,TAB,A,IEX)                                 8/06/63        PAGE 1

      SUBROUTINE GUESS(E,ET,NT,TAB,A,IEX)
      DIMENSION ET(100),TAB(100)
      IF(E-ET(1))11,12,13
   11 IEX=2
      IT=2
      GC TO 15
   12 A=TAB(1)
      IEX=1
      RETURN
   13 DC 14 I=2,NT
      IT=I
      IF(E-ET(I))15,131,14
  131 A=TAB(I)
      IEX=1
      GC TO 100
   14 CCNTINUE
      IEX=3
      IT=NT
   15 A=TAB(IT-1)+(TAB(IT)-TAB(IT-1)) *((E-ET(IT-1))/(ET(IT)-ET(IT-1)))
  100 RETURN
      END(1,0,0,1,0,0,0,0,0,1,0,0,0,0,0)
```

```
FUNCTION FUNCT(EE,EF,N)
FUNCT=CONGO(EE)*ELSI(EE,N)*(4.0-EF/EE*(4.0+3.0*LOGF(EE/EF)))/1.25
RETURN
END(1,0,0,1,0,0,0,0,0,1,0,0,0,0,0)
```

SUBROUTINE INPUT

8/06/63 PAGE 1

```
      SUBROUTINE INPUT
      DIMENSION PROB(12),CELEM(12)                                     0227
      DIMENSION Z(12),BU(100,12),AU(100,12),DOSCON(100),EF(100),T(12), 0228
     1LCC(12),BUNM(12),AUNM(12),B(12),M(12)
      DIMENSION B1(100,12),B2(100,12),B3(100,12),B4(100,12),DOSV(350), 0230
     1DOMEGA(350)                                                      0231
      DIMENSION ELEM(12)                                               0232
      COMMON NEXA,Z1                                                   0233
      COMMON EE,BU,AU,DOSCON,NTBL,NM,NX,Z,T,XU,EEL,YU,EF               0234
      COMMON B1,B2,B3,B4,M                                             0235
      COMMON ELEM,ADOSEC                                               0236
  904 FORMAT(14HOPHOTON ENERGY,5X,15HDOSE CONVERSION,7X,12HATTEN. COEF.,0237
     16X,56HBUILDUP COEF. FOR FORM B=A1*E**(-B1*U*T)+A2*E**(-B2*U*T)/5X,0238
     25H(MEV),10X,1H(,A6,8H)/E FLUX,8X,9HCM**2/GM.,16X,2HA1,12X,2HB1,12X0239
     3,2HA2,12X,2HB2)                                                  0240
  900 FORMAT(A6,E12.0)                                                 0241
  901 FORMAT(34HO UPPER LIMIT OF ELECTRON ENERGY =1PE11.3,15H  LOWER LIM0253
     1IT =1PE11.3/31H  UPPER LIMIT ON GAMMA ENERGY = 1PE11.3)          0261
  902 FORMAT(36HOINPUT DATA FOR EACH SHIELD MATERIAL )                 0262
  903 FORMAT(14HO FOR MATERIAL I4,9H WHICH IS A6,19H WITH ATOMIC NUMBER 0264
     1I4)                                                              0268
  905 FORMAT(1H 1PE13.6,1PE21.6,1PE19.6,6X,1P4E14.6)                   0269
  907 FORMAT(1H1)                                                      0242
 1000 FORMAT(2I6,3E12.0,I6)                                            0243
 1001 FORMAT(6E12.0)                                                   0247
 1002 FORMAT(4E12.0)                                                   0245
 1500 FORMAT(5E12.0)                                                   0244
      READ INPUT TAPE 5,1000,NM,NTBL,XU,YL,YU ,NEXA                    0246
      EEL = YL                                                         0248
      READ INPUT TAPE 5,1001,(EF(I),I=1,NTBL)                          0249
      DO 2222 IM=1,NM                                                  0250
      READ INPUT TAPE 5,900, ELEM(IM),Z(IM)
 2223 READ INPUT TAPE 5,1002,(B1(I,IM),B2(I,IM),B3(I,IM),B4(I,IM),     0252
     1I=1,NTBL)                                                        0254
 2222 READ INPUT TAPE 5,1001,(AU(I,IM),I=1,NTBL)                       0255
      READ INPUT TAPE 5,900,ADOSEC                                     0257
      READ INPUT TAPE 5,1001,(DOSCON(I),I=1,NTBL)                      0258
      WRITE OUTPUT TAPE 6,901,XU,EEL,YU                                0259
      WRITE OUTPUT TAPE 6,902                                          0260
      DO 2 IM=1,NM                                                     0263
      IZ=Z(IM)                                                         0265
      WRITE OUTPUT TAPE 6,903,IM,ELEM(IM),IZ                           0266
      WRITE OUTPUT TAPE 6,904,ADOSEC                                   0267
      WRITE OUTPUT TAPE 6,905,(EF(I),DOSCON(I),AU(I,IM),B1(I,IM),      0270
     1B2(I,IM),B3(I,IM),B4(I,IM),I=1,NTBL)                             0271
    2 WRITE OUTPUT TAPE 6,907                                          0272
      RETURN                                                           0273
      END(1,0,0,1,0,0,0,0,0,1,0,0,0,0,0)                               0274
```

```
      FUNCTION SINGL(EB,N)                                               8/06/63        PAGE 1

      FUNCTION SINGL(EB,N)                                               0278
      DIMENSION PROB(12),CELEM(12)                                       0279
      DIMENSION Z(12),BU(100,12),AU(100,12),DOSCON(100),EF(100),T(12),
     1LOC(12),BUNM(12),AUNM(12),B(12),M(12)                              0281
      DIMENSION B1(100,12),B2(100,12),B3(100,12),B4(100,12),DOSV(350),   0282
     1DOMEGA(350)                                                        0283
      DIMENSION ELEM(12)                                                 0284
      COMMON NEXA,Z1                                                     0285
      COMMON EE,BU,AU,DOSCON,NTBL,NM,NX,Z,T,XU,EEL,YU,EF                 0286
      COMMON B1,B2,B3,B4,M                                               0287
      COMMON ELEM,ADOSEC                                                 0288
   10 FORMAT(23H1ERROR IN TABLE NUMBER I6,10X,6HVALUE E12.5,22H IS OUT O 0303
     1F TABLE RANGE)                                                     0304
      I=1                                                                0289
      PISUM=1.0                                                          0290
      DO 3 J=1,NX                                                        0291
      IM=M(J)                                                            0292
      CALL GUESS(EB,EF,NTBL,BU(1,J),BUNM(J),IEX)                         0293
      GO TO (1,21,21),IEX                                                0294
   21 IF(NEXA)2,1,2                                                      0295
    1 CALL GUESS(EB,EF,NTBL,AU(1,IM),AUNM(J),IEX)                        0296
      PISUM=BUNM(J)*EXPF(-AUNM(J)*T(J))*PISUM                            0297
    3 CONTINUE                                                           0298
      CALL GUESS(EB,EF,NTBL,DOSCON,A,IEX)                                0299
    4 SINGL=PISUM*A                                                      0300
      RETURN                                                             0301
    2 WRITE OUTPUT TAPE 6,10,I,EB                                        0302
      CALL EXIT                                                          0305
      END(1,0,0,1,0,0,0,0,0,1,0,0,0,0,0)
```

```
      SUBROUTINE DITTO (XU,YL,YU,H,AMAG,N,ERR,ANS,HX,HY)
      DIMENSION FY(5),YP(5)
      PVOLUM=0.0
      R2=YL
      ANS=0.0
      DX=0.0
      HX=0.0
      HY=0.0
      K=0
      PAGC=AMAG*1.0E-4
    1 Y=YL
      HYMAX=ABSF((YU-YL)/4.0)
      S=ABSF(HY)
      DC 35 I=1,5
      K=K+1
      CALL XINTG(H,Y,PAGC,XU,N,ERR,AREA,DX)
      FY(I)=AREA
      IF(K-1)10,5,10
    5 DXMIN=DX
      DX=ABSF(DX)
      HY=ABSF((YU-YL)/(XU-Y))*DX
      IF(YU-YL)6,10,10
    6 HY=-HY
      S=ABSF(HY)
   10 IF (I-1)25,15,25
   15 IF(S-HYMAX)25,25,20
   20 HY=HYMAX
   25 YP(I)=Y
      Y=Y+HY
      IF (DXMIN-DX)35,30,30
   30 DXMIN=DX
      IF(K-1)35,31,35
   31 HYMIN=HY
   35 CONTINUE
      DC 40 I=1,5
      T=YP(I)
      GY=SINGL(T,N)
      FY(I)=FY(I)*GY
   40 CCNTINUE
      CALL YINTG(FY,YL,HY,ERR,PAGC,YU,M,FHY,PVOLUM)
      IF (M-1) 41,50,41
   41 IF (HYMIN-FHY)50,50,45
   45 HYMIN=FHY
   50 GC TO (55,60,65),M
   55 ANS=ANS+PVOLUM
      HX=DXMIN
      HY=HYMIN
      YL=R2
      RETURN
   60 ANS=ANS+PVOLUM
      YL=YL+4.0*HY
      HY=FHY
      GC TO 1
   65 HY=FHY
```

35

```
GC TO 1
END(1,0,0,1,0,0,0,0,0,1,0,0,0,0,0)
```

```
      SUBROUTINE XINTG(H,Y,PAGC,XU,N,ERR,AREA,P)
      DIMENSION FX(5)
      R=H
      X=Y
      AREA=0.0
      LAST=0
      IFLAG=0
      IF(XU-X)8,35,13
    8 H=-H
      IFLAG=1
   13 P=H
    2 GRET=((X+(4.0*H)-XU))
      X2=X
      IF(IFLAG-1)7,1,7
    1 IF(GRET)3,6,5
    7 IF(GRET)5,6,3
    3 H=(XU-X)/4.0
    6 LAST=1
    5 FX(1)=FUNCT(X,Y,N)
      DC 10 I=2,5
      X=X+H
      FX(I)=FUNCT(X,Y,N)
   10 CCNTINUE
      S1=((2.0*H)/3.0)*(FX(1)+4.0*FX(3)+FX(5))
      S2=(H/3.0)*(FX(1)+4.0*FX(2)+2.0*FX(3)+4.0*FX(4)+FX(5))
      S3=S2-S1
      S3=ABSF(S3)
      S4=ABSF(S2)
      RATIO=(S3/(MAX1F(S4,PAGC)))*(1.0/ERR)
      IF(H)11,12,12
   11 IFLAG=1
   12 IF(RATIO-1.0)20,15,15
   15 H=H/1.5
      LAST = 0
      X=X2
      GO TO 2
   20 IF (P-H)21,21,19
   19 P=H
   21 IF(LAST-1)22,46,22
   22 IF(RATIO-.5)25,30,30
   25 IF(RATIO-.01)40,46,46
   30 H=H/1.5
      GC TO 46
   40 H=H*1.5
      GC TO 46
   46 AREA=AREA+S2+(1.0/15.0)*(S2-S1)
      IF (LAST-1)2,35,2
   35 H=R
      RETURN
      END(1,0,0,1,0,0,0,0,0,1,0,0,0,0,0)
```

```
      SUBROUTINE YINTG(FY,HL,HY,ERR,PAGC,YU,M,FHY,PVOLUM)
      DIMENSION FY(5)
      M=2
      DIST=HL+((4.0*HY)-YU)
      IF(HY)1,6,5
    1 IF(DIST)2,3,4
    5 IF(DIST)4,3,2
    2 FHY=(YU-HL)/4.0
    6 M=3
      GO TO 35
    3 M=1
    4 S1=((2.0*HY)/3.0)*(FY(1)+4.0*FY(3)+FY(5))
      S2=(HY/3.0)*(FY(1)+4.0*FY(2)+2.0*FY(3)+4.0*FY(4)+FY(5))
      S3=S2-S1
      S3=ABSF(S3)
      S4=ABSF(S2)
      RATIO=(S3/(MAX1F(S4,PAGC)))*(1.0/ERR)
      IF (RATIO-1.0)20,15,15
   15 FHY=HY/1.5
      M=3
      GC TO 35
   20 IF (M-1)21,45,21
   21 IF (RATIO-.5)25,30,30
   25 IF (RATIO-.01)40,41,41
   30 FHY=HY/1.5
      GC TO 45
   40 FHY=HY*1.5
      GC TO 45
   41 FHY=HY
   45 PVOLUM=S2+(1.0/15.0)*(S2-S1)
   35 RETURN
      END(1,0,0,1,0,0,0,0,0,1,0,0,0,0,0)
```

38

SAMPLE INPUT DATA

39

```
*     DATA                                                                  0702
   2     20       10.        0.1        10.      1                          0703
         .1        .2         .3         .4          .5          .6         0704
         .7        .8         .9        1.0         1.5          2.         0705
         3.        4.         5.         6.          7.          8.         0706
         9.       10.                                                       0707
AL     13.                                                                  0708
        8.0      -.11        -7.       .044      B1,B2,B3,B4                0709
        8.0      -.11        -7.       .044      AS A FCT. OF               0710
        8.0      -.11        -7.       .044      MATERIAL                   0711
        8.0      -.11        -7.       .044      ALUMINUM                   0712
        8.0      -.11        -7.       .044      ALUMINUM                   0713
        8.0      -.11        -7.       .044      ALUMINUM                   0714
        8.0      -.11        -7.       .044      ALUMINUM                   0715
        8.0      -.11        -7.       .044      ALUMINUM                   0716
        8.0      -.11        -7.       .044      ALUMINUM                   0717
        8.0      -.11        -7.       .044      ALUMINUM                   0718
       6.75      -.094       -5.75     .069                                 0719
        5.5      -.082       -4.5      .093                                 0720
        4.5      -.074       -3.5      .116                                 0721
        3.8      -.066       -2.8      .130                                 0722
        3.4      -.065       -2.4      .141                                 0723
        3.1      -.064       -2.1      .152                                 0724
        2.7      -.063       -1.7      .150                                 0725
        2.3      -.062       -1.3      .150                                 0726
       2.27      -.061       -1.27     .139                                 0727
       2.25      -.060       -1.25     .128                                 0728
       .169       .122        .104     .093         .084        .078        0750
       .073       .068        .065     .061         .050        .043        0751
       .035       .031        .028     .026         .025        .024        0752
       .023       .023       AL ATTENU.                                     0753
 TISSUES.                                                                   0729
        24.      -.14        -23.       0.       B1,B2,B3,B4                0730
        24.      -.14        -23.       0.       B1,B2,B3,B4                0731
        24.      -.14        -23.       0.       B1,B2,B3,B4                0732
        24.      -.14        -23.       0.       B1,B2,B3,B4                0733
        24.      -.14        -23.       0.       AS A FCT OF MAT CH         0734
       21.5      -.125       -20.5                                          0735
       17.5      -.116       -16.5                                          0736
        15.      -.113       -14.                                           0737
```

```
        12.        -.106      -11.       .005                         0738
        11.        -.104      -10.       .034                         0739
         7.8       -.088      - 6.8      .075                         0740
         6.4       -.076      - 5.4      .092                         0741
         5.2       -.062      - 4.2      .108                         0742
         4.5       -.056      - 3.5      .117                         0743
         4.0       -.052      - 3.0      .121                         0744
         3.6       -.050      - 2.6      .124                         0745
         3.3       -.047      - 2.3      .126                         0746
         3.0       -.045      - 2.0      .128                         0747
         2.8       -.043      - 1.8      .129                         0748
         2.7       -.042      - 1.7      .130                         0749
        .163        .132       .115      .100      .0936     .0867    0754
       .0812       .0761      .0722     .0683      .0556     .0478    0755
       .0384       .0329      .0292     .0267      .0250     .0233    0756
       .0223       .0212       CH2 ATTENU.                            0757
 R/HR                                                                 0758
    1.695-6      1.72-6     1.81-6    1.84-6    1.841-6   1.839-6    0759
     1.82-6     1.805-6     1.79-6    1.73-6    1.595-6    1.47-6    0760
     1.27-6      1.19-6    1.111-6   1.046-6     1.02-6    1.00-6    0761
      9.8-7       9.4-7                                               0762
  NASA SAMPLE PROBLEM
     2    -1      1     1     1  0  0  .  1.0    .5    13.0  APLLO GUT4
     2    0.5
     1    5.0           0.5
     2    1.0           0.5
     2    0.5
     1    2.0           0.5
     2    2.0           0.5
```

SAMPLE OUTPUT DATA

ELECTRON BREMSSTRAHLUNG RADIATION DOSE STUDY

UPPER LIMIT OF ELECTRON ENERGY = 1.000E 01 LOWER LIMIT = 10.000E-02
UPPER LIMIT ON GAMMA ENERGY = 1.000E 01

INPUT DATA FOR EACH SHIELD MATERIAL

FOR MATERIAL 1 WHICH ISAL WITH ATOMIC NUMBER 13

| PHOTON ENERGY (MEV) | DOSE CONVERSION (R/HR )/E FLUX | ATTEN. COEF. CM**2/GM. | BUILDUP COEF. FOR FORM B=A1*E**(-B1*U*T)+A2*E**(-B2*U*T) A1 | B1 | A2 | B2 |
|---|---|---|---|---|---|---|
| 10.000000E-02 | 1.695000E-06 | 1.690000E-01 | 8.000000E 00 | -1.100000E-01 | -7.000000E 00 | 4.400000E-02 |
| 2.000000E-01 | 1.720000E-06 | 1.220000E-01 | 8.000000E 00 | -1.100000E-01 | -7.000000E 00 | 4.400000E-02 |
| 3.000000E-01 | 1.810000E-06 | 1.040000E-01 | 8.000000E 00 | -1.100000E-01 | -7.000000E 00 | 4.400000E-02 |
| 4.000000E-01 | 1.840000E-06 | 9.300000E-02 | 8.000000E 00 | -1.100000E-01 | -7.000000E 00 | 4.400000E-02 |
| 5.000000E-01 | 1.841000E-06 | 8.400000E-02 | 8.000000E 00 | -1.100000E-01 | -7.000000E 00 | 4.400000E-02 |
| 6.000000E-01 | 1.839000E-06 | 7.800000E-02 | 8.000000E 00 | -1.100000E-01 | -7.000000E 00 | 4.400000E-02 |
| 7.000000E-01 | 1.820000E-06 | 7.300000E-02 | 8.000000E 00 | -1.100000E-01 | -7.000000E 00 | 4.400000E-02 |
| 8.000000E-01 | 1.805000E-06 | 6.800000E-02 | 8.000000E 00 | -1.100000E-01 | -7.000000E 00 | 4.400000E-02 |
| 9.000000E-01 | 1.790000E-06 | 6.500000E-02 | 8.000000E 00 | -1.100000E-01 | -7.000000E 00 | 4.400000E-02 |
| 1.000000E 00 | 1.730000E-06 | 6.100000E-02 | 8.000000E 00 | -1.100000E-01 | -7.000000E 00 | 4.400000E-02 |
| 1.500000E 00 | 1.595000E-06 | 5.000000E-02 | 6.750000E 00 | -9.400000E-02 | -5.750000E 00 | 6.900000E-02 |
| 2.000000E 00 | 1.470000E-06 | 4.300000E-02 | 5.500000E 00 | -8.200000E-02 | -4.500000E 00 | 9.300000E-02 |
| 3.000000E 00 | 1.270000E-06 | 3.500000E-02 | 4.500000E 00 | -7.400000E-02 | -3.500000E 00 | 1.160000E-01 |
| 4.000000E 00 | 1.199000E-06 | 3.100000E-02 | 3.800000E 00 | -6.600000E-02 | -2.800000E 00 | 1.300000E-01 |
| 5.000000E 00 | 1.111000E-06 | 2.800000E-02 | 3.400000E 00 | -6.500000E-02 | -2.400000E 00 | 1.410000E-01 |
| 6.000000E 00 | 1.046000E-06 | 2.600000E-02 | 3.100000E 00 | -6.400000E-02 | -2.100000E 00 | 1.520000E-01 |
| 7.000000E 00 | 1.020000E-06 | 2.500000E-02 | 2.700000E 00 | -6.300000E-02 | -1.700000E 00 | 1.500000E-01 |
| 8.000000E 00 | 10.000000E-07 | 2.400000E-02 | 2.300000E 00 | -6.200000E-02 | -1.300000E 00 | 1.500000E-01 |
| 9.000000E 00 | 9.300000E-07 | 2.300000E-02 | 2.270000E 00 | -6.100000E-02 | -1.270000E 00 | 1.390000E-01 |
| 1.000000E 01 | 9.400000E-07 | 2.300000E-02 | 2.250000E 00 | -6.000000E-02 | -1.250000E 00 | 1.280000E-01 |

FOR MATERIAL 2 WHICH ISTISSUE WITH ATOMIC NUMBER 5

| PHOTON ENERGY (MEV) | DOSE CONVERSION (R/HR )/E FLUX | ATTEN. COEF. CM**2/GM. | BUILDUP COEF. FOR FORM B=A1*E**(-B1*U*T)+A2*E**(-B2*U*T) A1 | B1 | A2 | B2 |
|---|---|---|---|---|---|---|
| 10.000000E-02 | 1.695000E-06 | 1.630000E-01 | 2.400000E 01 | -1.400000E-01 | -2.300000E 01 | 0. |
| 2.000000E-01 | 1.720000E-06 | 1.320000E-01 | 2.400000E 01 | -1.400000E-01 | -2.300000E 01 | 0. |
| 3.000000E-01 | 1.810000E-06 | 1.150000E-01 | 2.400000E 01 | -1.400000E-01 | -2.300000E 01 | 0. |
| 4.000000E-01 | 1.840000E-06 | 10.000000E-02 | 2.400000E 01 | -1.400000E-01 | -2.300000E 01 | 0. |
| 5.000000E-01 | 1.841000E-06 | 9.360000E-02 | 2.400000E 01 | -1.400000E-01 | -2.300000E 01 | 0. |
| 6.000000E-01 | 1.839000E-06 | 8.670000E-02 | 2.150000E 01 | -1.250000E-01 | -2.050000E 01 | -0. |
| 7.000000E-01 | 1.820000E-06 | 8.120000E-02 | 1.750000E 01 | -1.160000E-01 | -1.650000E 01 | -0. |
| 8.000000E-01 | 1.805000E-06 | 7.610000E-02 | 1.500000E 01 | -1.130000E-01 | -1.400000E 01 | -0. |
| 9.000000E-01 | 1.790000E-06 | 7.220000E-02 | 1.200000E 01 | -1.060000E-01 | -1.100000E 01 | 5.000000E-03 |
| 1.000000E 00 | 1.730000E-06 | 6.830000E-02 | 1.100000E 01 | -1.040000E-01 | -1.000000E 01 | 3.400000E-02 |
| 1.500000E 00 | 1.595000E-06 | 5.560000E-02 | 7.800000E 00 | -8.800000E-02 | -6.800000E 00 | 7.500000E-02 |
| 2.000000E 00 | 1.470000E-06 | 4.780000E-02 | 6.400000E 00 | -7.600000E-02 | -5.400000E 00 | 9.200000E-02 |
| 3.000000E 00 | 1.270000E-06 | 3.840000E-02 | 5.200000E 00 | -6.200000E-02 | -4.200000E 00 | 1.080000E-01 |
| 4.000000E 00 | 1.190000E-06 | 3.290000E-02 | 4.500000E 00 | -5.600000E-02 | -3.500000E 00 | 1.170000E-01 |
| 5.000000E 00 | 1.111000E-06 | 2.920000E-02 | 4.000000E 00 | -5.200000E-02 | -3.000000E 00 | 1.210000E-01 |
| 6.000000E 00 | 1.046000E-06 | 2.670000E-02 | 3.600000E 00 | -5.000000E-02 | -2.600000E 00 | 1.240000E-01 |
| 7.000000E 00 | 1.020000E-06 | 2.500000E-02 | 3.300000E 00 | -4.700000E-02 | -2.300000E 00 | 1.260000E-01 |
| 8.000000E 00 | 10.000000E-07 | 2.330000E-02 | 3.000000E 00 | -4.500000E-02 | -2.000000E 00 | 1.280000E-01 |
| 9.000000E 00 | 9.800000E-07 | 2.230000E-02 | 2.800000E 00 | -4.300000E-02 | -1.800000E 00 | 1.290000E-01 |
| 1.000000E 01 | 9.400000E-07 | 2.120000E-02 | 2.700000E 00 | -4.200000E-02 | -1.700000E 00 | 1.300000E-01 |

NASA SAMPLE PROBLEM

BREMSSTRAHLUNG WITH SPECTRUM 1

| SECTOR | DOSE R/HR | MATERIALS AND THICKNESSES IN GM/CM**2 | | | |
|---|---|---|---|---|---|
| 1 | 0.1253E-07 | AL | 5.00 | TISSUE | 1.00 |
| 2 | 0.1421E-07 | AL | 2.00 | TISSUE | 2.00 |

VEHICLE APLLO ANALYSIS, INTERIOR DOSE AT GUT4

| SECTOR | DOSE | D OMEGA |
|---|---|---|
| 1 | 0.12535E-07 | 0.50000E 00 |
| 2 | 0.14208E-07 | 0.50000E 00 |

THE TOTAL DOSE IS 0.13371E-07 R/HR WITH SPECTRUM 1

## REFERENCES


1. Mar, B., "The Calculation of Bremsstrahlung Radiation Penetrating a Space Vehicle," The Boeing Company, Document D2-90411, 1963.

2. Simonsen, R. H., "Specialized Double Integral Evaluation," Applied Mathematics Information Center, The Boeing Company Report AS-0949, November 1961.

3. Wyard, S. J., Proceedings of the Physical Society A, 65, 377, 1952.

4. Barton, J. A., Dye, D. L., Mar, B. W., and Pearson, M. D., "Dyna Soar Space Radiation Shielding," The Boeing Company, Document D2-80034, April 1961.

5. Zerby, C. D., and Moran, H. S., "Tissue Dose Rate from Bremsstrahlung Radiation Behind an Idealized Apollo Vehicle Wall Exposed to Electrons in the Artificial Radiation Belt," Oak Ridge National Laboratory, Document ORNL 62-10-29, August 1962.

6. Etherington, H., <u>Nuclear Engineering Handbook</u>, Mc-Graw-Hill, New York, 1958.